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2D/3D Face Recognition US Army Final Report

Prepared for:

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14. ABSTRACT
Traditional biometric research over the past 20 years has focused primarily on the ability to recognize subjects in two scenarios: identification and verification. Verification is the process that attempts to confirm the identity of a given individual (i.e., John Smith presents his passport to the gate-agent to verify that he really is John Smith). This process is usually very quick and easy to perform on the computing power available today. Conversely, identification is a process that attempts to locate an unknown subject given a list of individuals (i.e. US Terrorism Watch List). This process is very time consuming because each member on the watch list must be compared to the subject in question. In both of these processes, we have generally assumed that the images will display cooperative subjects in well-defined lighting environments. In the real world, this is not the case. While it is assumed that subjects will be cooperative during an initial enrollment phase (such as getting a driver's license, going through a checkpoint, or walking through an x-ray machine), this is usually not the case for future acquisition attempts. When attempting to identify an individual at a later time (especially at a distance and without their knowledge in a covert scenario), these "probe" images are generally non-frontal facing, in uncontrolled lighting, and at an unknown distance. When standard recognition algorithms are executed on this variable dataset, results are typically very poor.

In this project we developed a complete solution for 3D based 2D facial recognition that leverages existing research and previously developed code by domain experts at the University of Southern California and Progeny Systems. To verify performance, we employed multiple public facial data sets acquired for the purpose of 2D and 3D facial recognition - most recently MultiPIE - which varied pose, illumination, and expression. Combined, these data sets will allow us to

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quantitatively benchmark and report comparative results under a variety of "challenging" conditions, which we feel to be representative of conditions in the field.

15. SUBJECT TERMS					
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Agenda

- Project Objectives
- 2D/3D Face Recognition
  - Image Preprocessing
  - Gallery Enrollment
  - Probe Processing
  - 2D/3D Face Recognition
  - Surveillance
  - Graphical User Interface
- Summary & Demonstration
- Project Questions / Discussion

Project Objectives

- #1 - Reconstruct a 3D Face Model for external visualization and subject enrollment
  - Given 5 images (-90, -45, 0, 45, 90)
- #2 - Develop an approach for high performance Frontal & Non-Frontal face recognition given a single probe image
- #3 - Develop a Video / IP Video interface to offer human detection and surveillance capabilities to the operator
- #4 - Develop a Web Services interface for future expansion & integration
- #5 - Develop a Graphical User Interface to demonstrate the capabilities of the prototype system

2D / 3D Face Recognition

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- Objective: Develop algorithms to create and leverage 3D facial images to improve uncooperative, long range 2D face recognition
- The best commercial face recognition algorithms require frontal faces with at least 45 pixels between the eyes to be successful
  - These methods have accuracy between 10-25% at a 1% false accept rate when presented with multi-angle, long range images
  - Our approach will drastically improve these results to more than 90% acceptance at a 1% false accept rate (and potentially even better through the use of our novel subject indexing technique)
- Provided 5 enrollment images (-90, -45, 0, 45, 90)
  - Previously captured for drivers licenses, passports, prison intake, etc.





2D / 3D Face Recognition

- Goal: Use the 3D model to generate all possible synthetic poses of the individual (i.e. looking up and to the right, walking with head as a profile, etc.)
- Once enrolled, any image taken in the wild should match (or be able to match) to the enrolled 3D image with a high similarity score
- Novel technologies created for this project:
  - Multi-Pose (-90 .. 90) Head Detection in Imagery
  - Automatic landmark location (i.e. find the eyes, nose, mouth, etc.)
  - 3D face construction from single or multiple 2D images
  - Lighting compensation algorithms (the 3D model is key to allowing us to simulate and compensate for all potential lighting environments)
  - Most importantly: Improved multi-angle multi-pose 2D face recognition for non-cooperative subjects

Materials and Data Sets

- **Multi-PIE (CMU): Multiple Pose, Illumination, and Expression**
  - 337 subjects, 19 illumination conditions, 15 viewpoints, 4 imaging sessions, 6 expressions
  - ~755,370 images

- **FRGC v2:**
  - 4,003 subjects, controlled / uncontrolled illumination, multiple modalities (2D and 3D images)
  - ~50,000 recordings

- **FERET**
  - Varying pose and expression
  - ~14,051 images

Image Preprocessing

Face Detection and Pose Classification

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- First step that is required for model construction:

All images	105	100.00%
Correct	101	96.2%
Wrong*	4	3.8%
Miss	0	0%

Misclassified faces: the left two images were classified as frontal faces; and the right two images were classified as profile faces.

*Misclassified faces with angle between estimated pose and ground truth value higher than 45 degrees are considered as very wrong classification.

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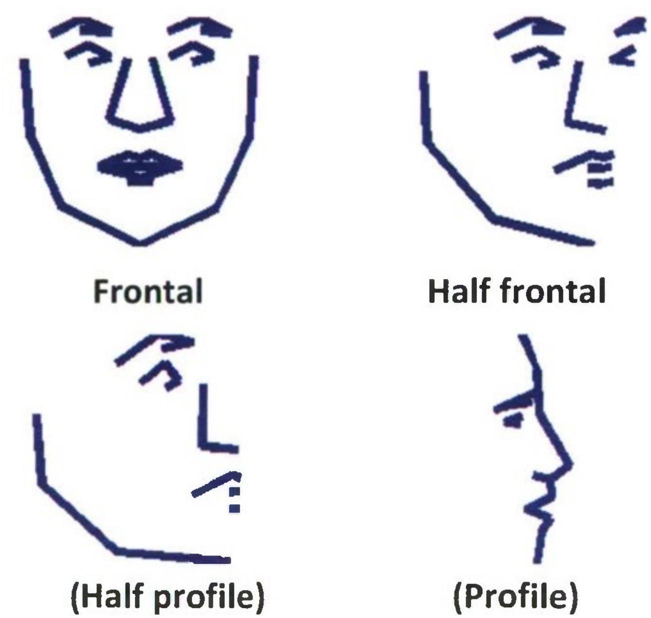
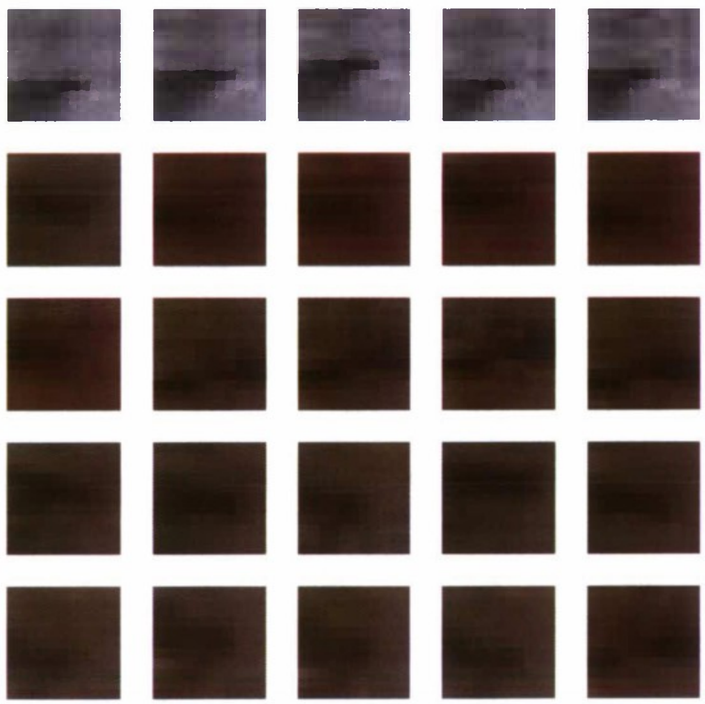
Landmark Detection - Building Training Sets

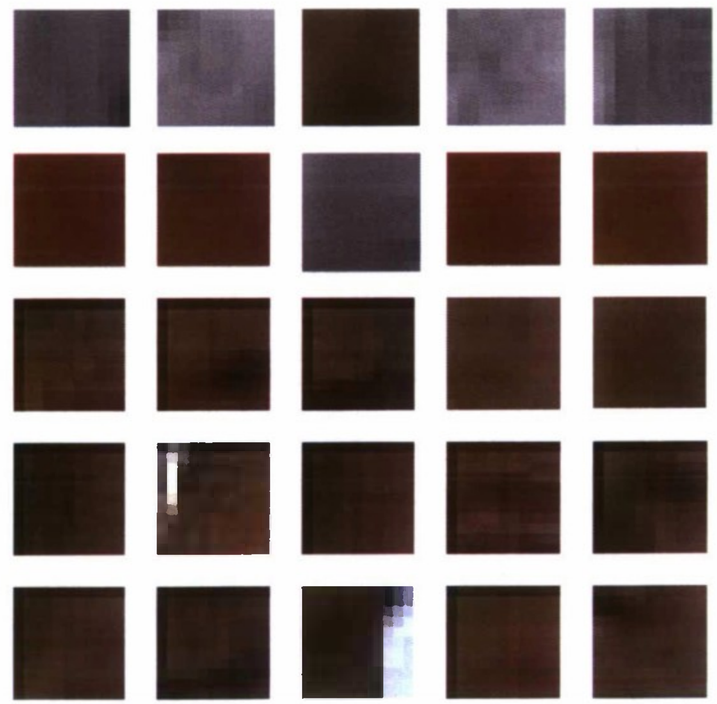
- Automatic landmark detection is accomplished through an exhaustive training procedure to learn many possible differences between human faces
- Initial Training Database : Color FERET
  - Contains a total of 11338 facial images collected between 1993 and 1996
  - 512 x 768 pixels, 13 different poses
  - We choose 308 x 4 images with neutral expression and no glasses
- Define Four Different Views
  - Frontal (39 points)
  - Half frontal 2 eyes (31 points)
  - Half profile 1 eye (22 points)
  - Profile (19 points)
- Required to most accurately represent the available facial features



Training Individual Points – Positive and Negative



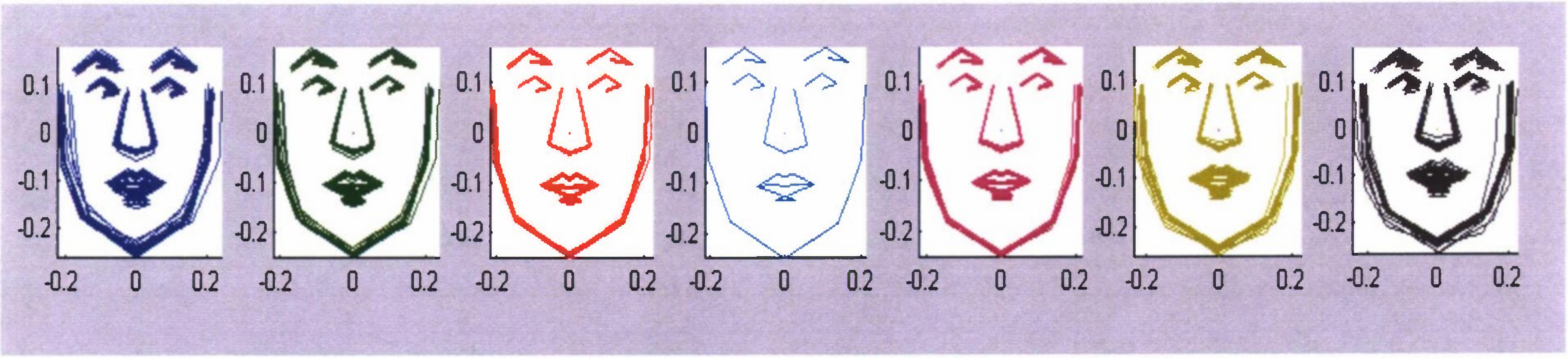
Positive



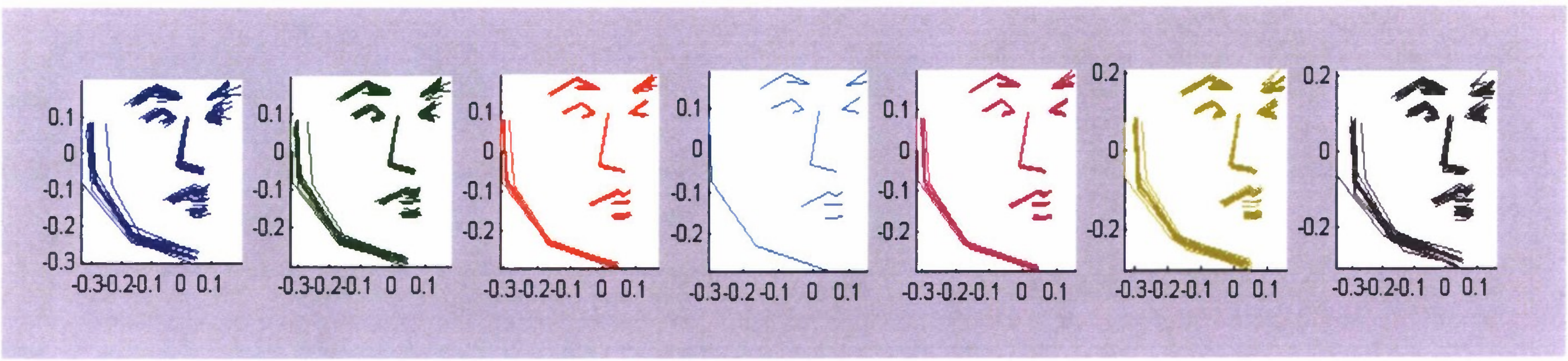
Negative

Shape model

- Result of training – error usually found in points on the jaw



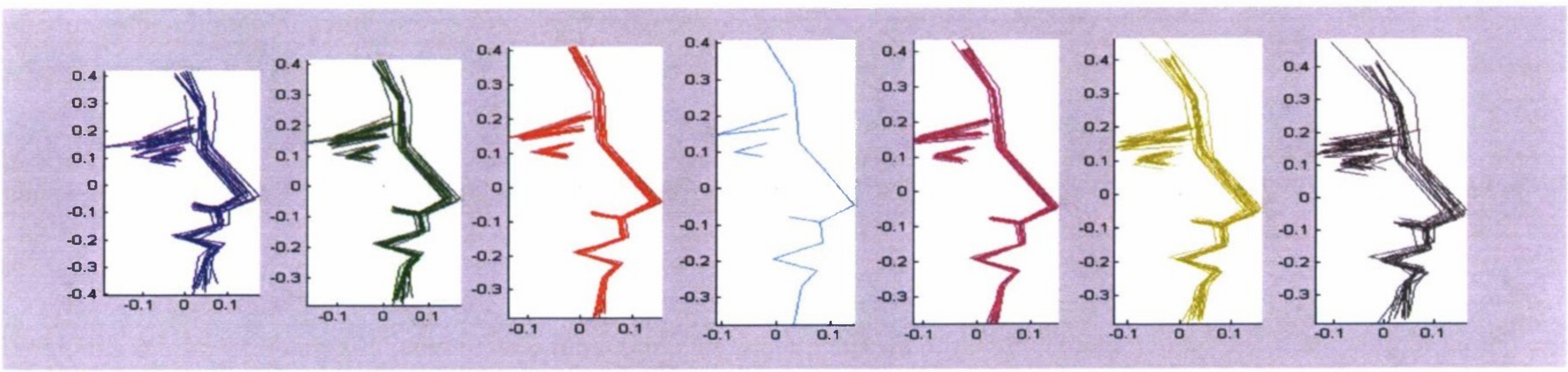
Frontal



Half-Frontal+

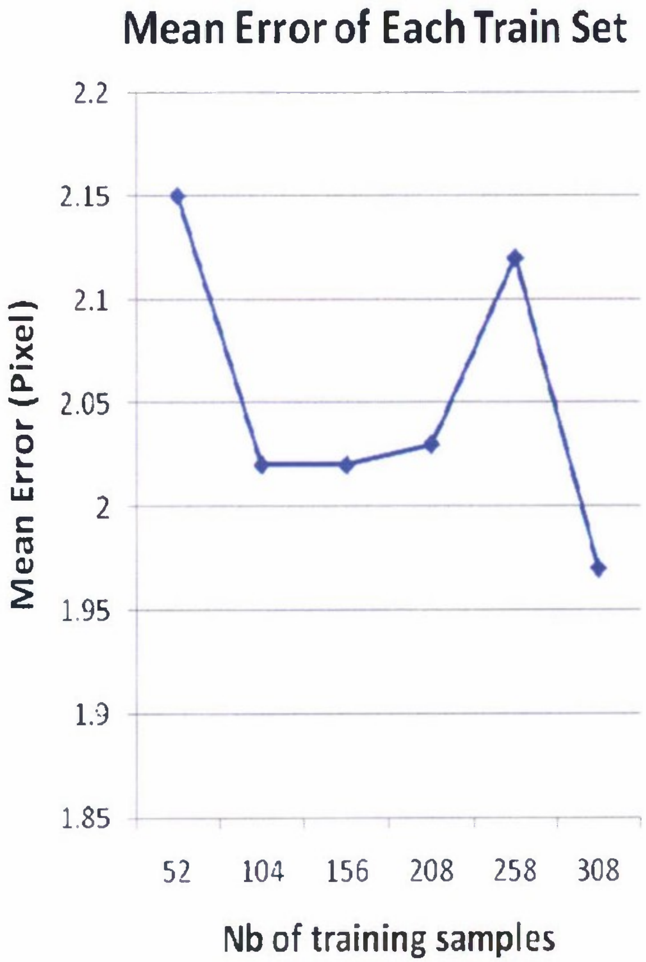
Shape model of profile

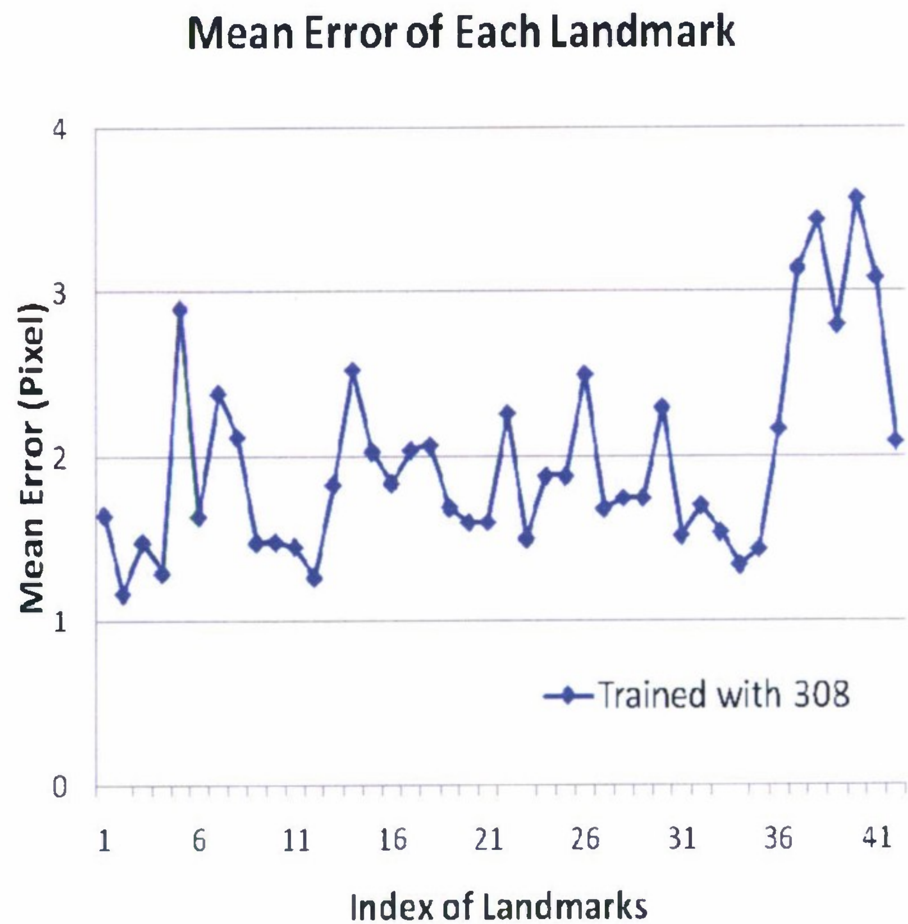
- Results show profile view is strongly dependent on pose
  - A subject at 90 degrees will have slightly different pixel locations than one at 75 degrees
  - Lack of symmetrical facial features complicates the task



Detector Performance (Frontal)

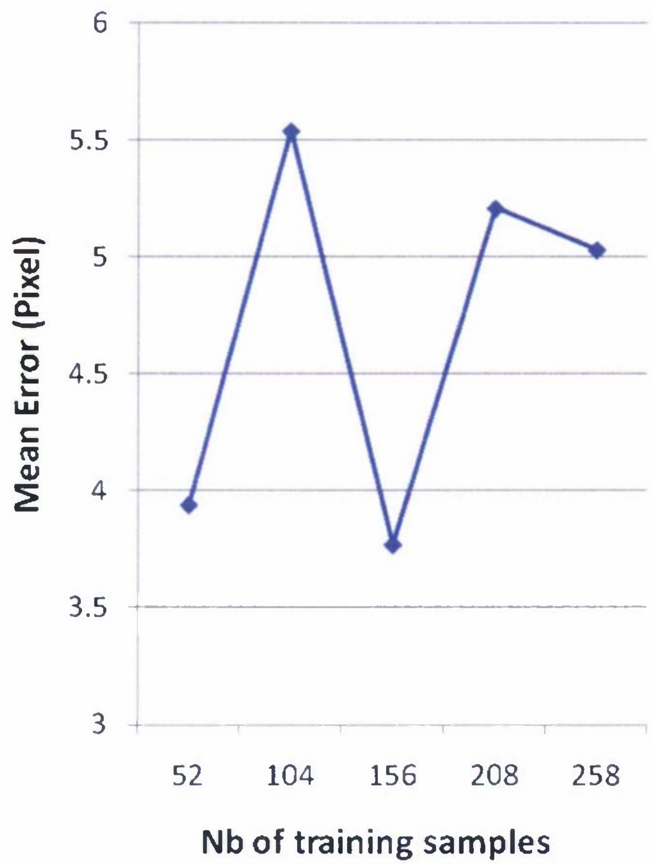
- Pixel error decreases with additional training
- Most error found in external (hard to classify) points

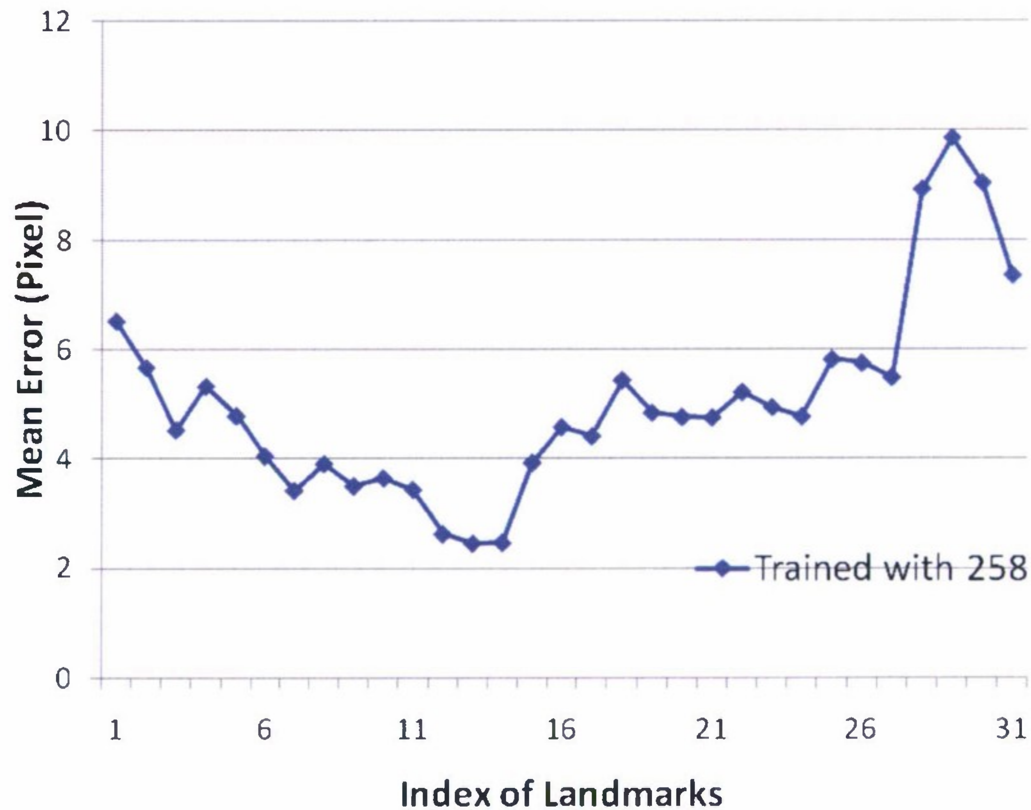




Detector Performance (Half Frontal)

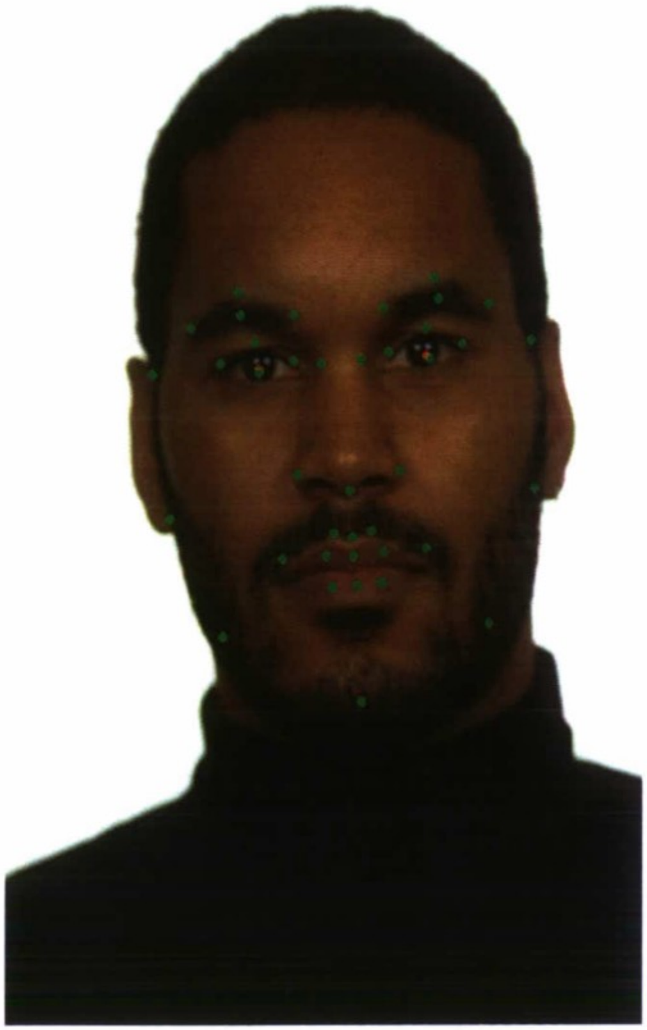
- Less accurate than frontal but overall mean error is less than 6 pixels





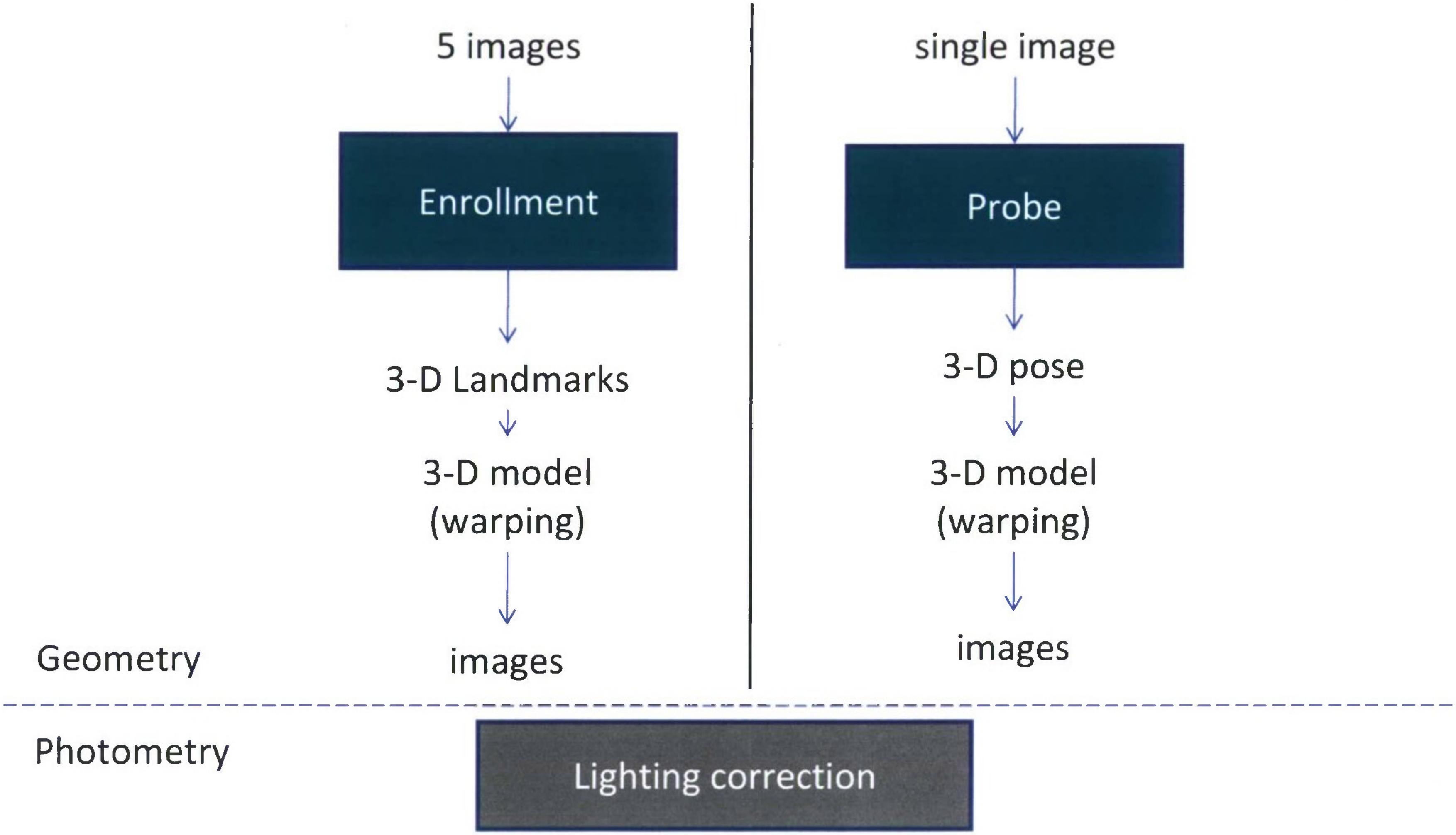
Automatically Detected Landmarks

- Points not exactly where they should be, but close enough for model construction



3D Creation Overview

- Two different processes dependent on available images



Flow Chart for Enrollment System

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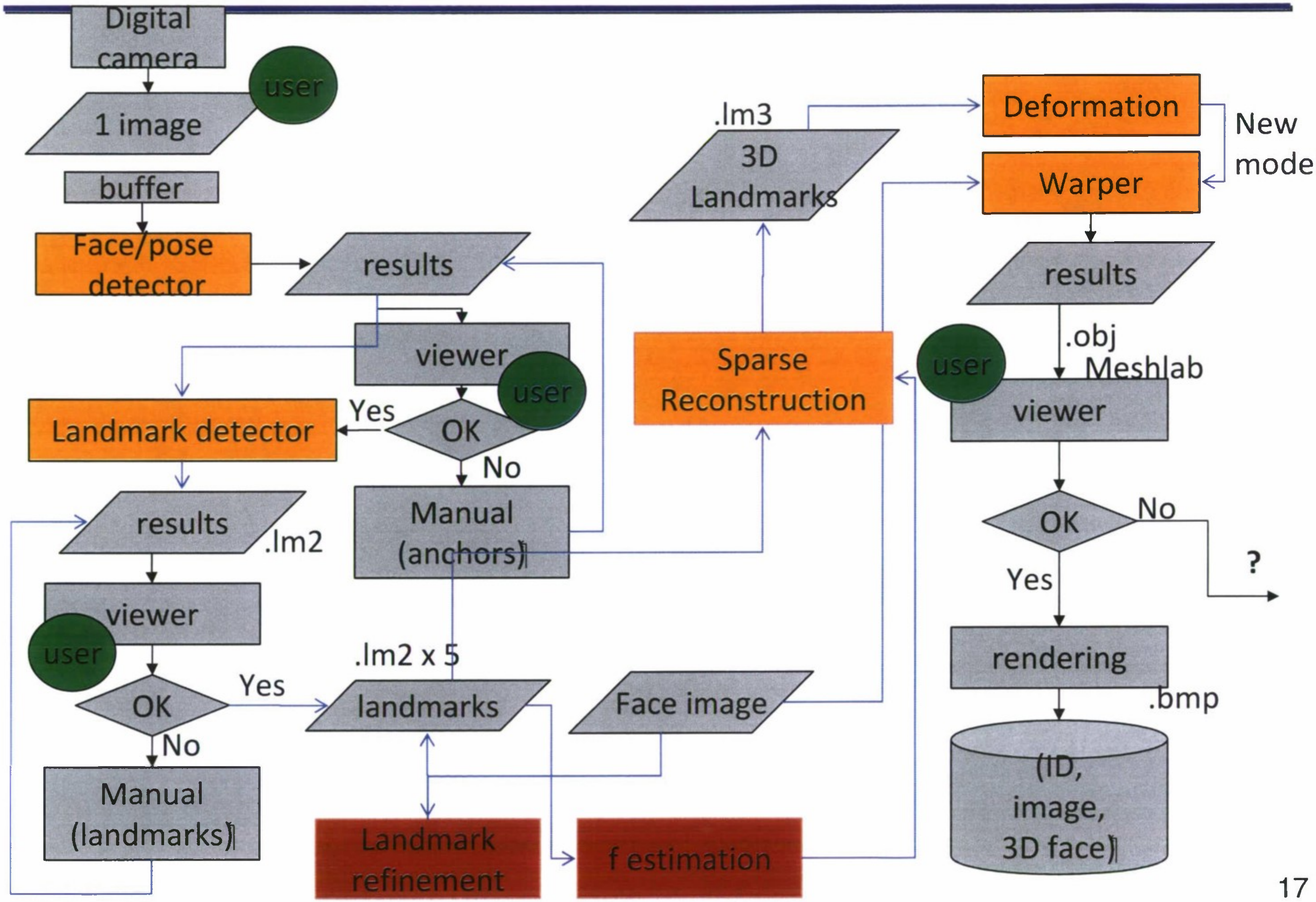
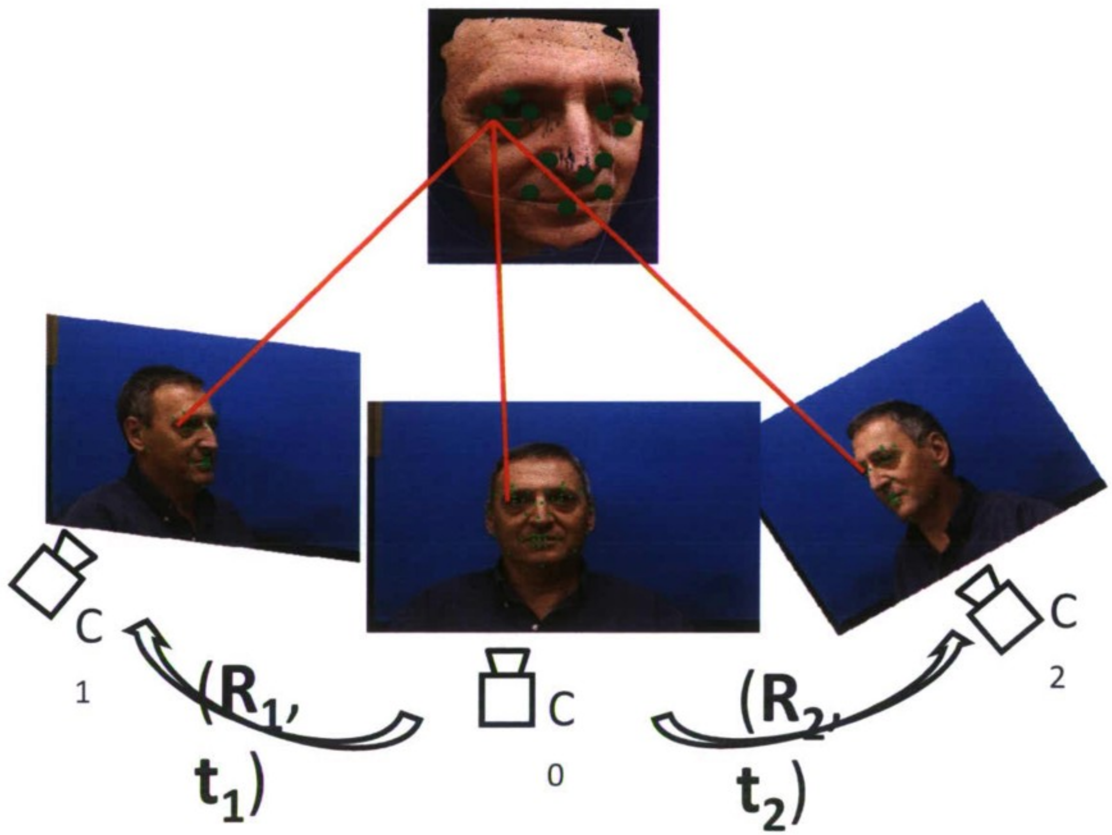
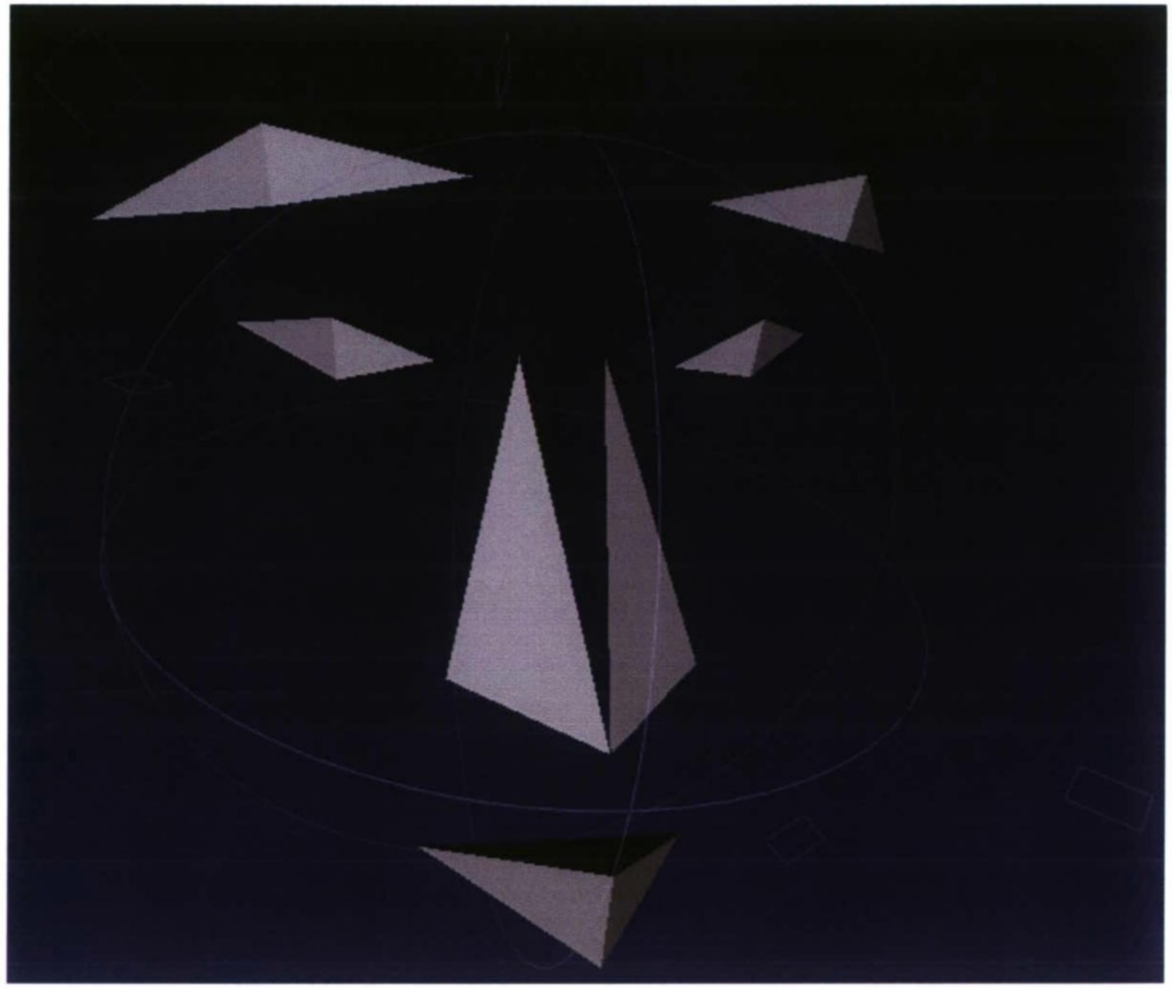


Sparse Bundle Adjustment

- Developed a novel way to adjust the automatically detected landmarks based on the correspondence between each of the different sets
  - Results in a very accurate 3D facial representation



Sparse Bundle Adjustment Result



3-D configuration of key landmarks used for facial deformation

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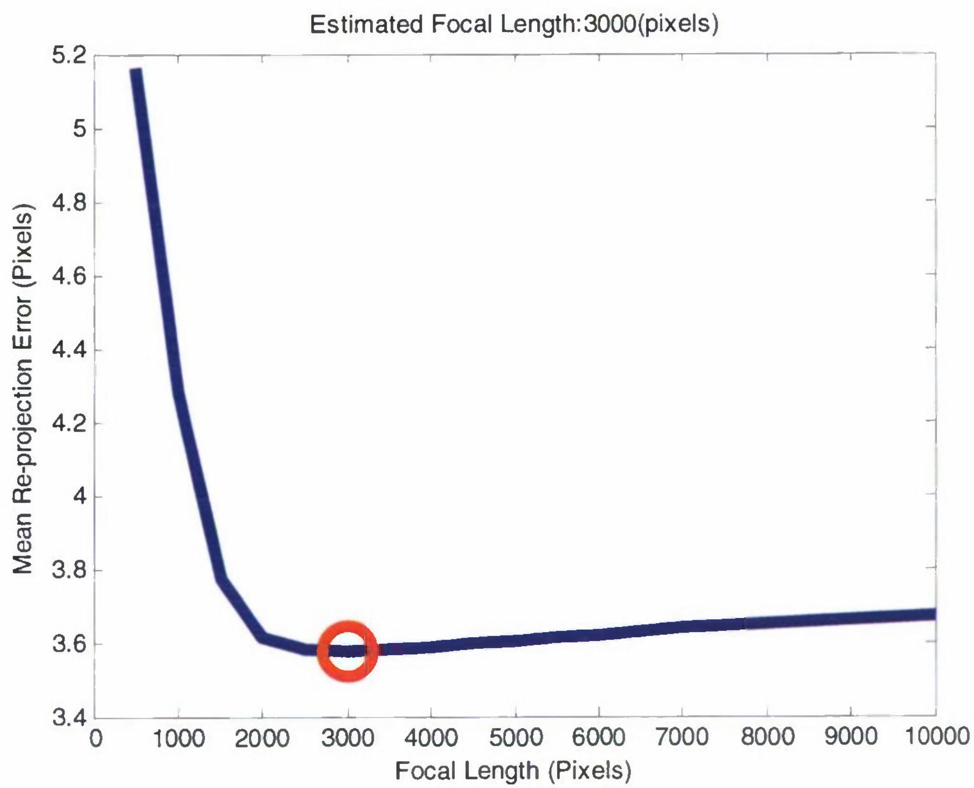
Automatic Focal Length Estimation

- Most challenging problem so far was the lack of focal length information available for existing BAT data
- Developed a novel method to automatically estimate the focal length by using the sparse bundle adjustment algorithm
- Results in more realistic depth in 3D models



Importance of Accurate Focal Length

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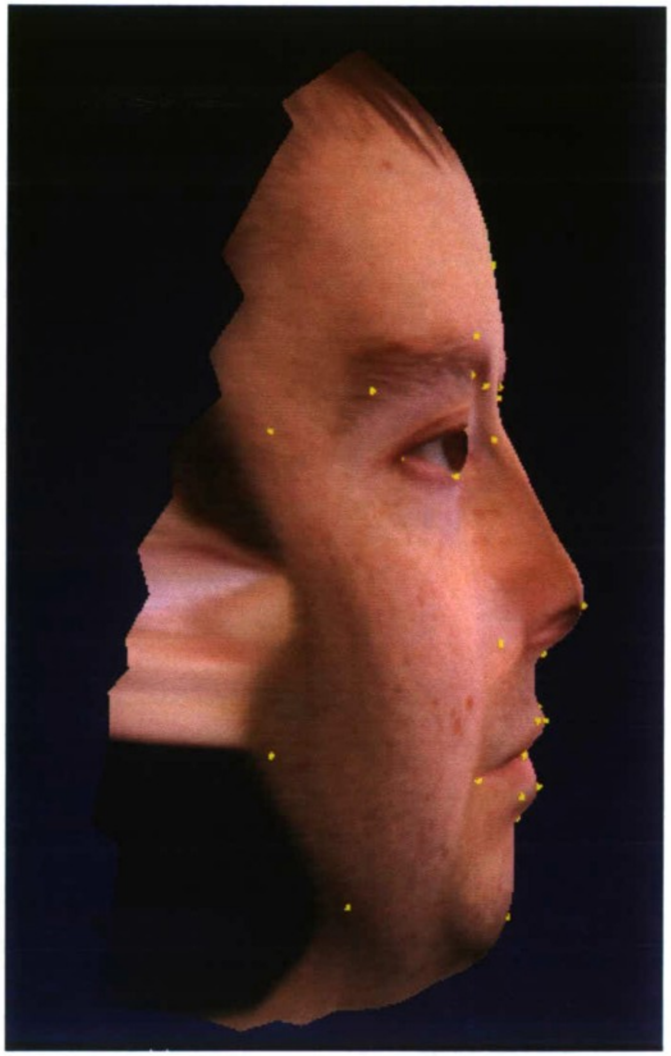
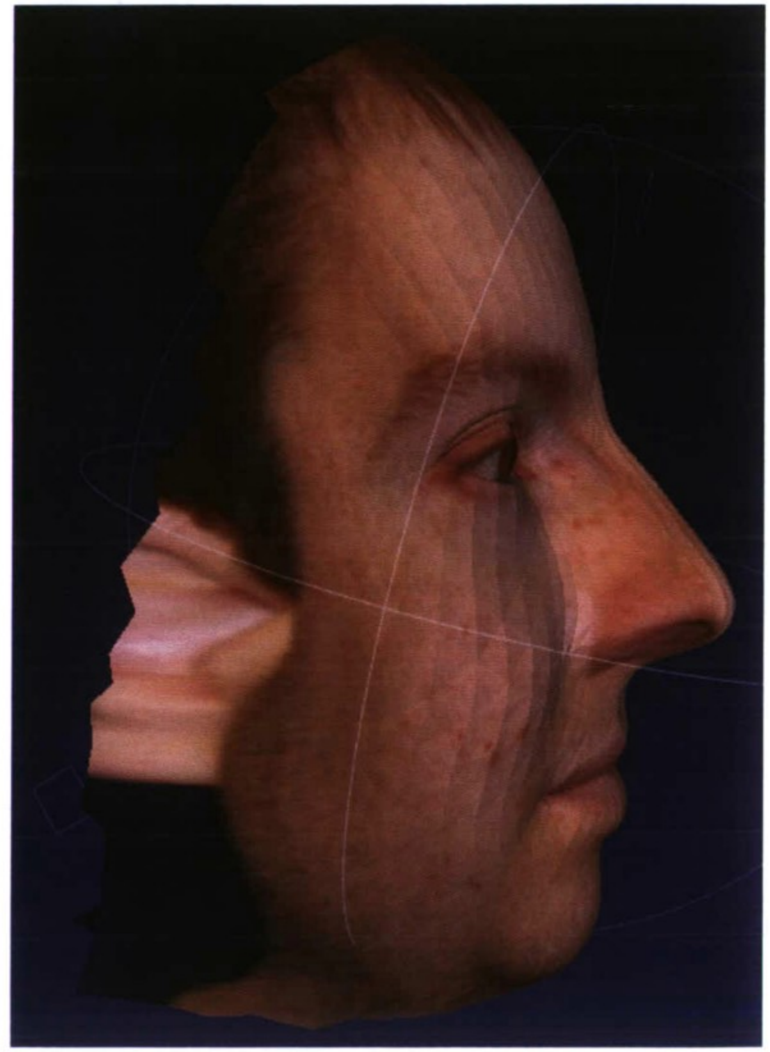

Incorrect Focal Length


Correct Focal Length

5 Image Enrollment Result

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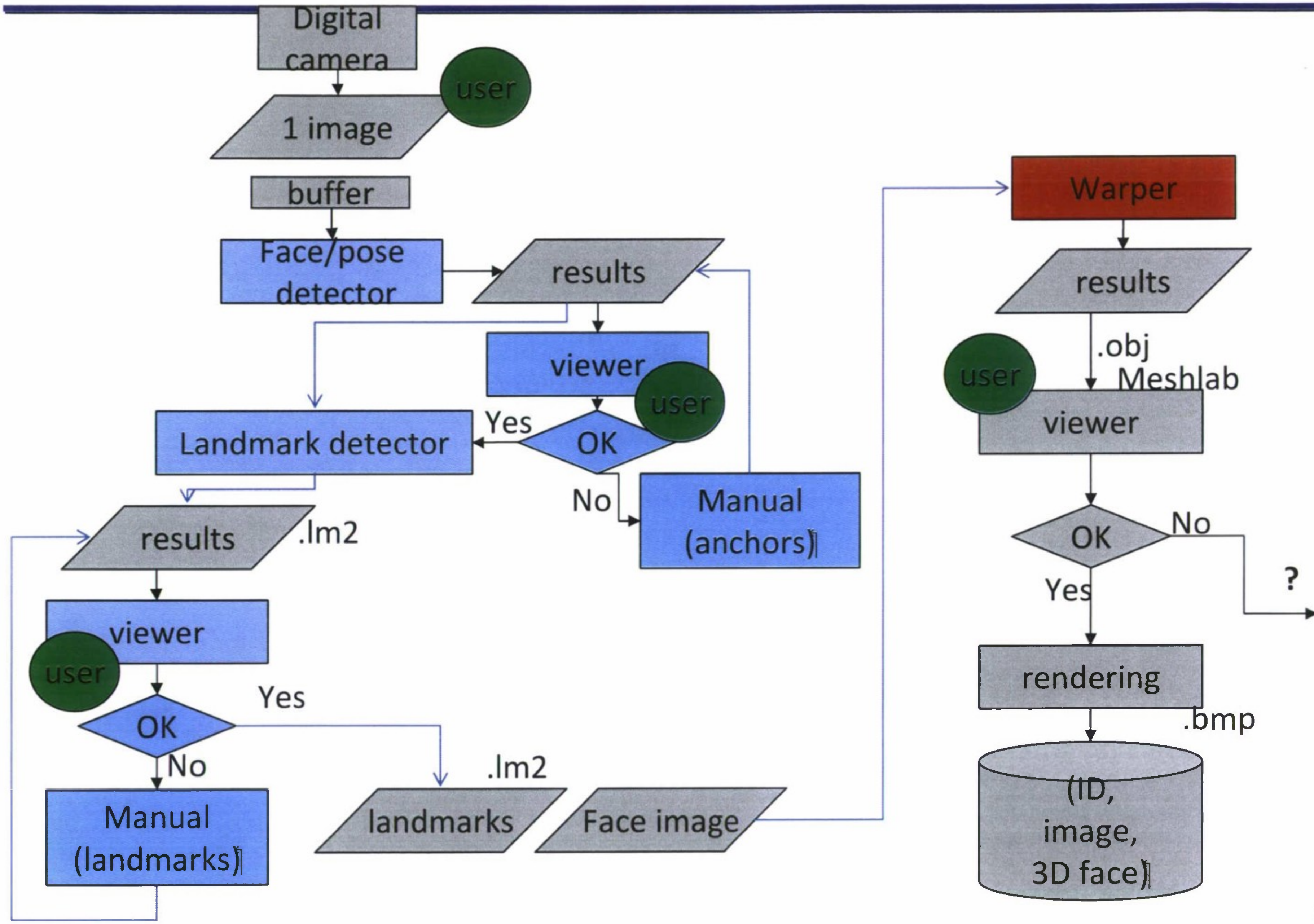
Original Images

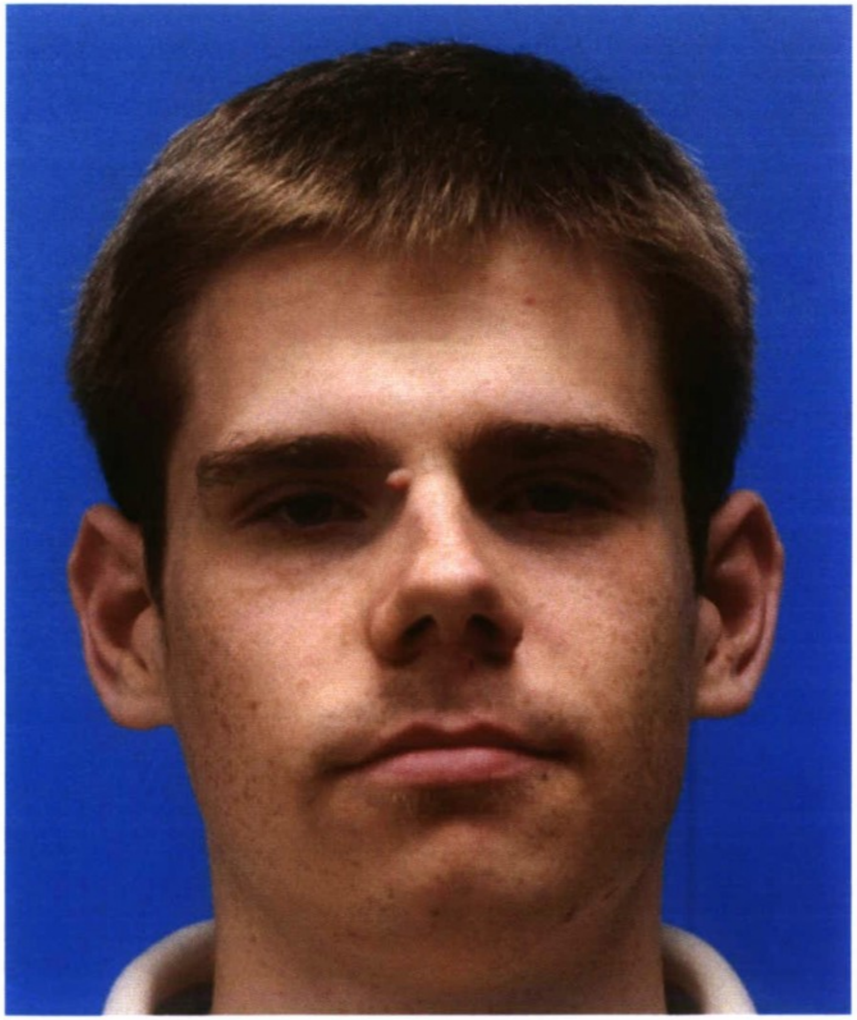
3D Reconstruction

Objective #1 – Met Successfully

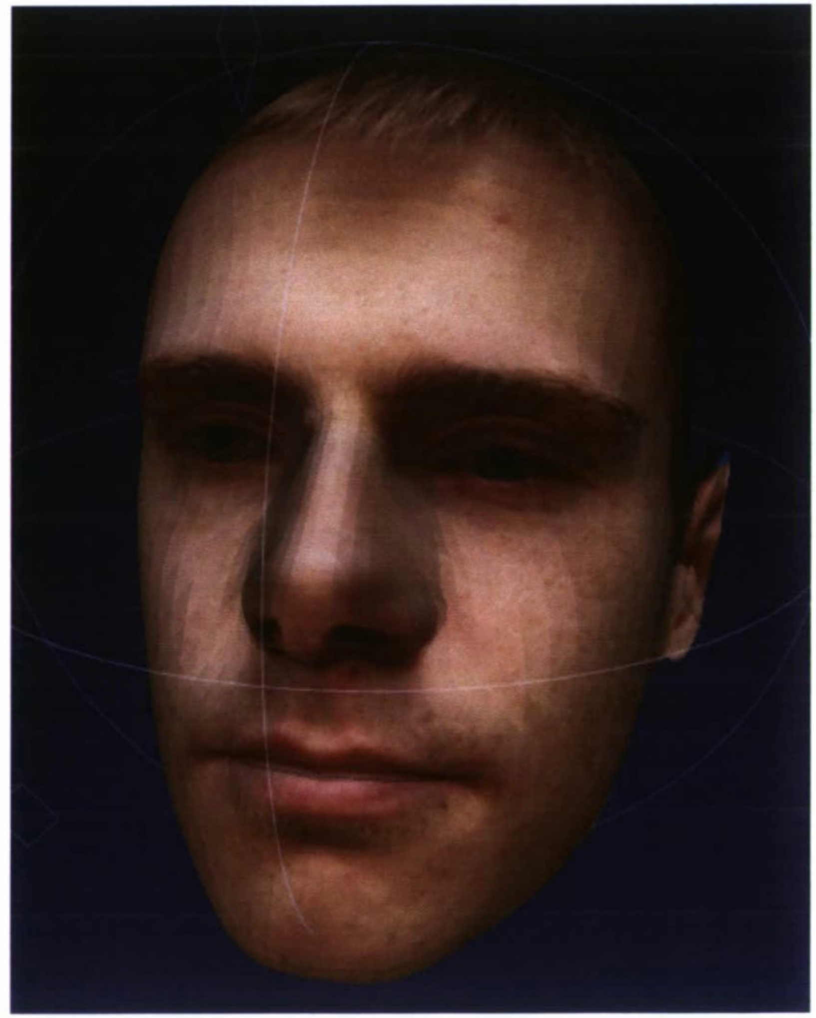
Flow Chart for Probe System



Single Image Probe Result

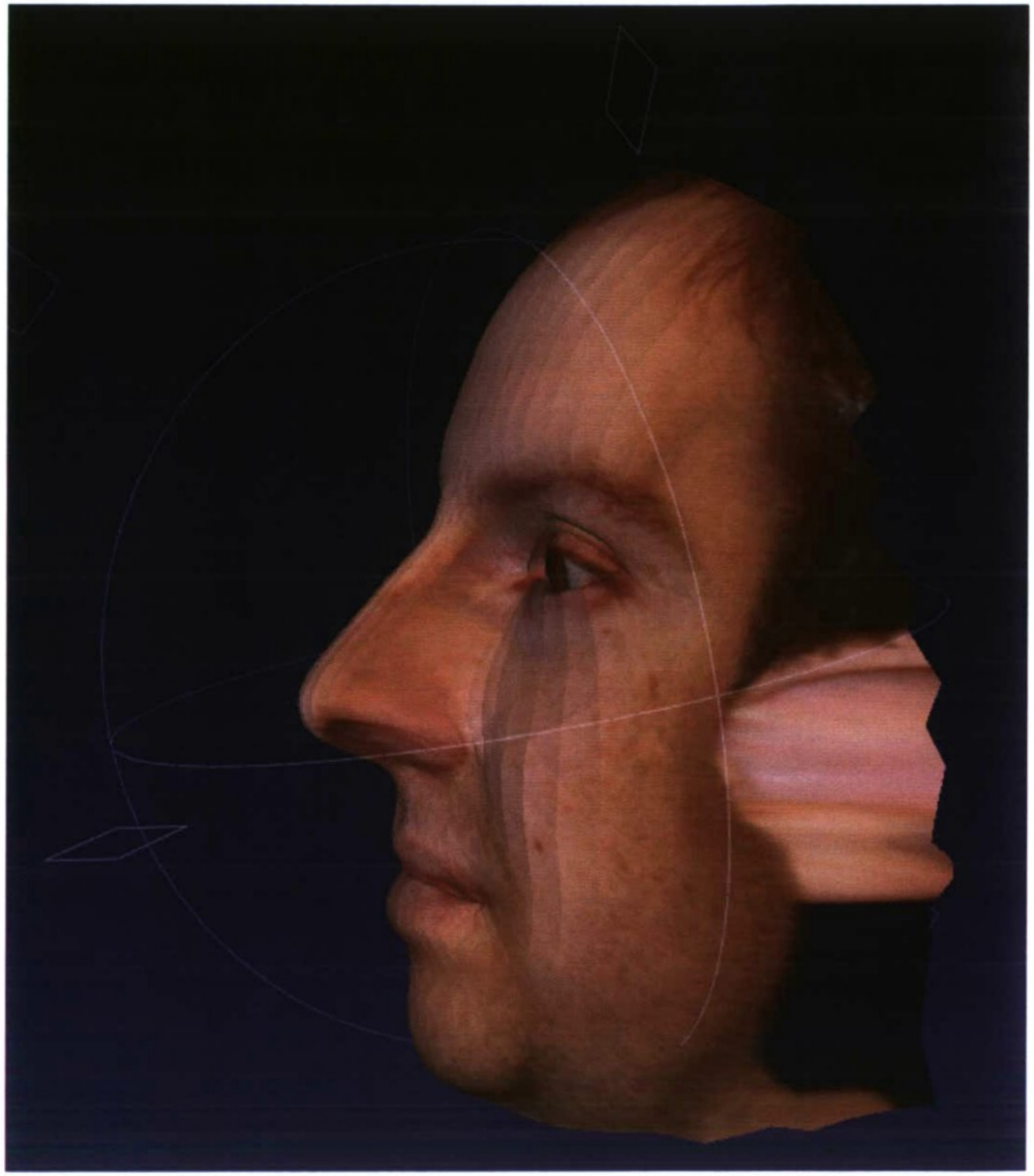


Original



3D Interpolation

3D Warp Issues – Image 0 Degrees



Facial structure and features are very accurate

- Note the warping error seen near the ear

- This is due to only a single frontal image being used for warping

- This artifact is not seen in the subsequent models

3D Warp Issues –Image 90 Degrees

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Even given a single probe image containing only one eye, a very realistic model can be constructed

- Through the use of piece-wise matching, highly accurate facial matches can be achieved

- This technique will eliminate the error due to over-rotation (i.e. >90 degrees) or inaccuracies in automatic landmark detection

2D / 3D Facial Recognition

- In order to use existing commercial face recognition engines, a frontal view must be automatically generated
  - Determined that while effective for minimal rotation (0-45 degrees), the technique fell apart on greater rotations (45-90).
- To improve performance, we propose a three phased approach for performing facial recognition
  - Step 1: Indexing based on facial structure and point landmarks
    - Allows us to immediately crop up to 90% of the database before performing facial matching (increased speed and fewer false accepts)
  - Step 2: Affine Facial Transformation
    - Given the fact that facial landmarks in each view correspond to each other (i.e. the nose is point 39 in the frontal view and is also point 39 in the profile view), directly warp the constructed triangles of the face to the nearest "45-degree bin" for matching (i.e. a 30 degree image would be matched to the 45)
  - Step 3: 3D Model Warping and Rotation
    - Use the constructed 3D model (found in the probe) to rotate the face to the nearest major bin (which is found every 45 degrees). Once there, match directly to that bin (i.e. 45 to 45) and fuse the results with Step 2

Step 1: Experiments – same IDs

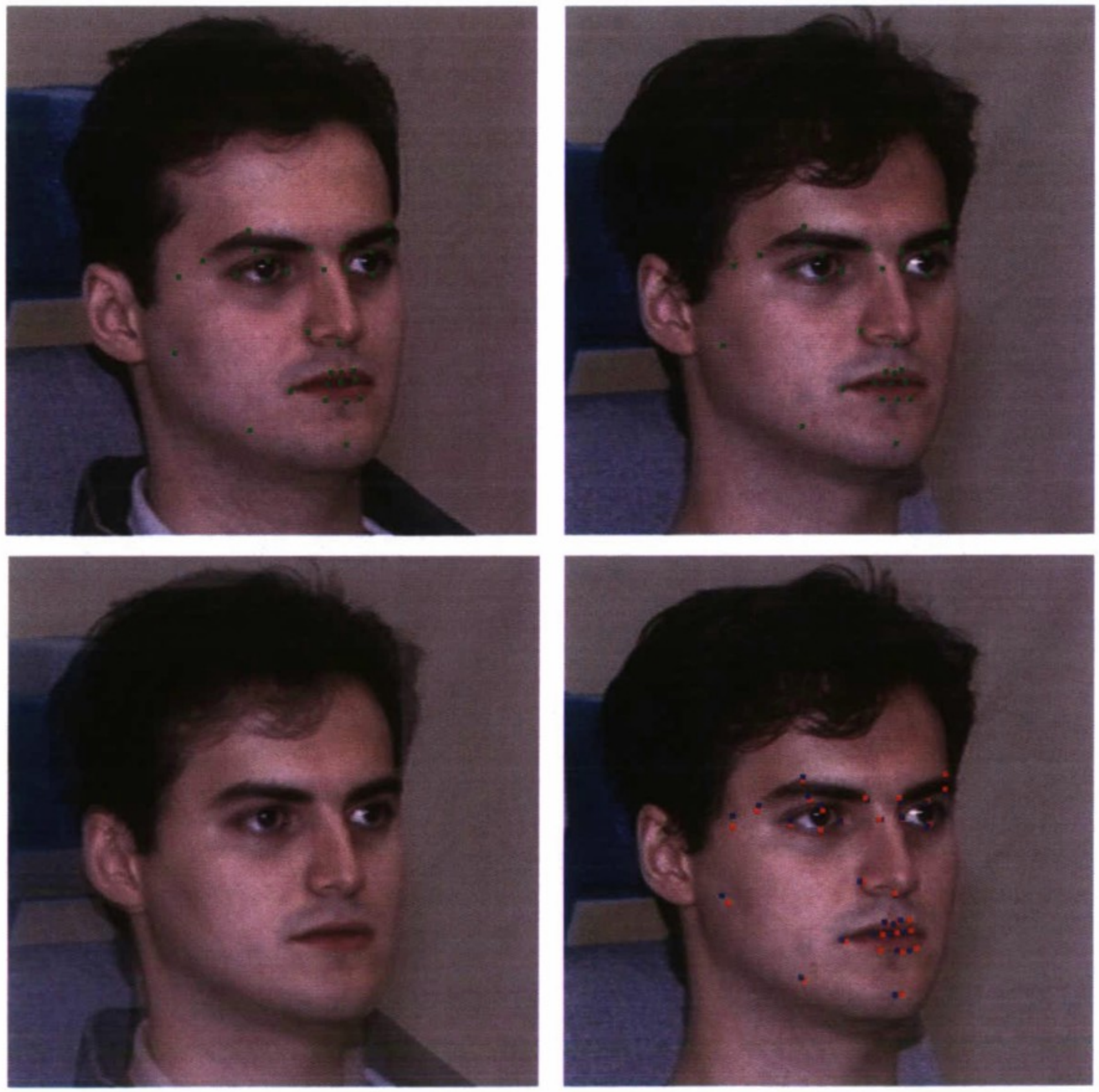
Points match very well – low MSE

-MSE_31=2.68

-MSE_27=2.23

-MSE_21=2.36

Step 1: Experiments – same IDs



MSE_31=2.50
MSE_27=2.01
MSE_21=1.78

Step 1: Experiments – different IDs

Significantly larger Pixel Error
-MSE_31=8.24
-MSE_27=6.51
-MSE_21=6.85

Step 1: Experiments – different IDs

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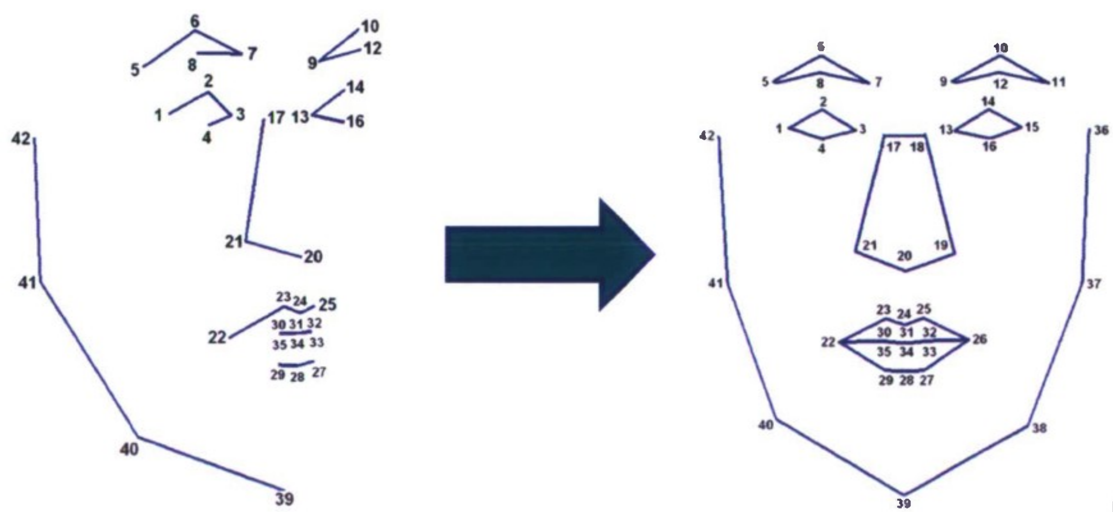
MSE_31=5.88
MSE_27=4.81
MSE_21=5.23

Step 2: Affine Rotation

- Perform rotation by deforming facial regions defined by feature points
- Exploit symmetry to interpolate data missing due to out-of-plane rotation
  - Allows us to always construct a frontal view regardless of the probe input pose



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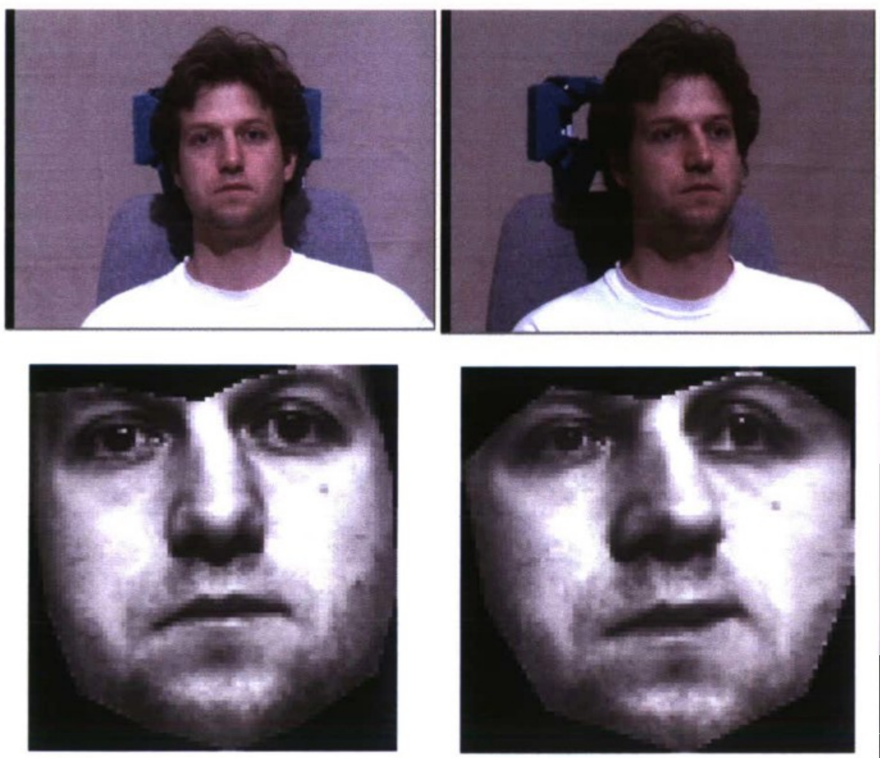
Affine Rotation Examples

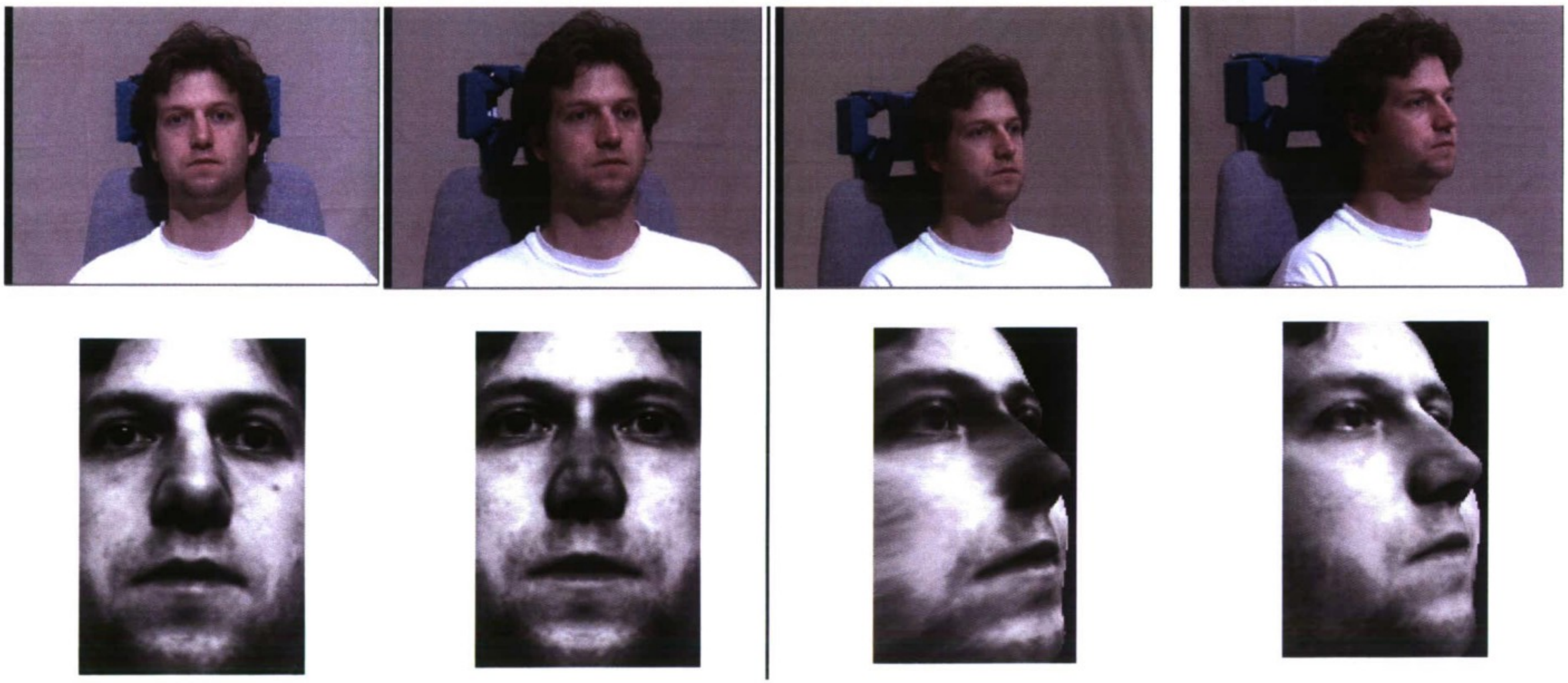
- Images below show the result of using our affine rotation algorithm and constructing a frontal & 45 degree view from the color input images on the top
- Note the similarity between each artificial frontal view


0 Bin


45 Bin

3D Model Rotation Examples

- This approach maps the face texture onto a 3D model using one or more input images (as previously described)
- Rotate the probe model to the nearest desired pose
- Benefit of this approach is that assuming the 3D construction was successful, any pose, rotation, and deformation is possible
  - Allows us to minimize the effect of facial expressions and account for yaw, pitch, and roll



0 Bin

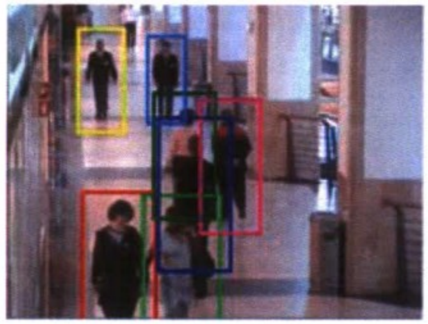
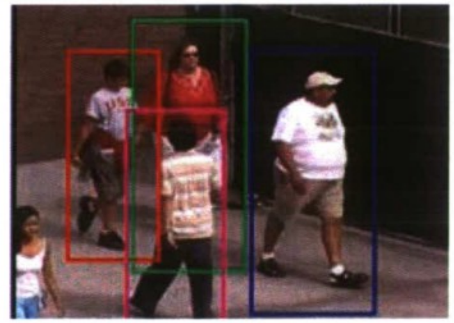
45 Bin

2D / 3D Face Recognition Summary

- After initial attempts to use the commercial software provided (Verilook), we determined that it was insufficient in meeting our high performance requirements
- Leveraged previously developed technology to create a fusion approach using the three strategies previously described
  - 0 degree probes - ~99% true accept rate at 1% false accept rate
    - Rank 5 Identification Rate – 100%
  - 45 degree probes - ~94% true accept rate at 1% false accept rate
    - Rank 5 Identification Rate – 98%
  - 60 degree probes - ~88% true accept rate at 1% false accept rate
    - Rank 5 Identification Rate – 96%
  - 90 degree probes - ~92% true accept rate at 1% false accept rate
    - Rank 5 Identification Rate – 98%
  - Note: Tested using the Multi-PIE dataset for all subjects that attended at least two days of acquisition
- Spiral development is still actively being performed to further improve the our recognition performance and 3D model construction accuracy
  - Would like to get a more complete copy of the BAT dataset for "real-world" testing

Objective #2 – Met Successfully

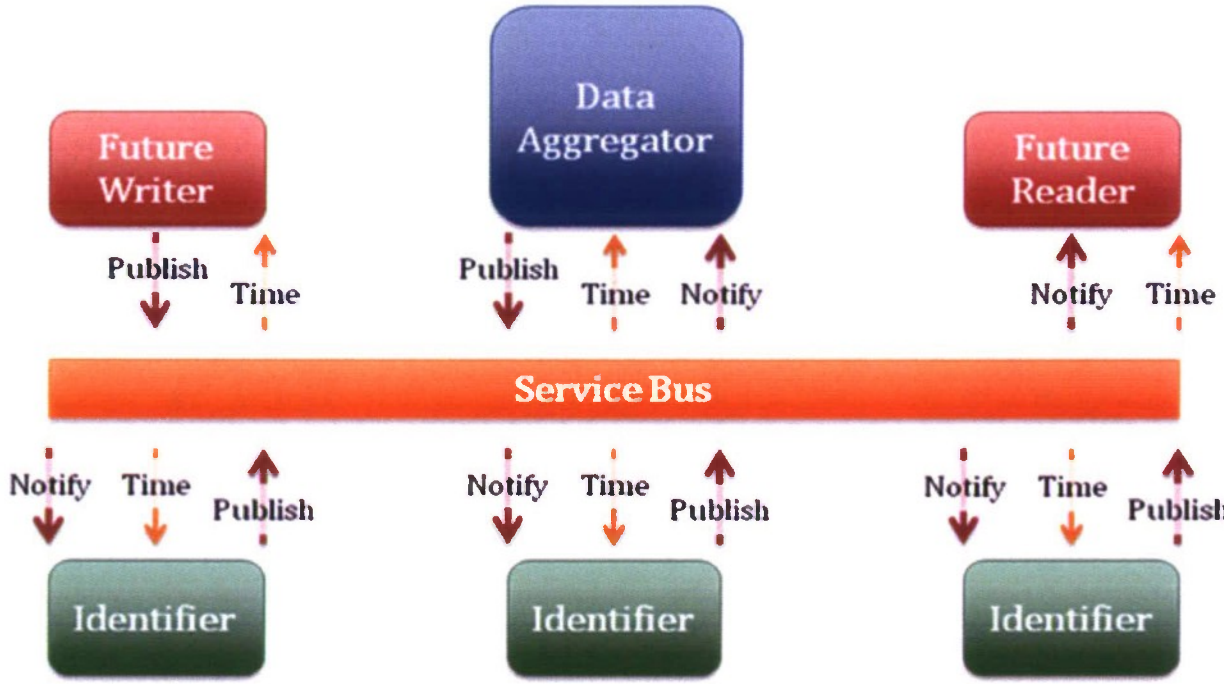
Video / IP Video Surveillance

- Leverages existing research by Progeny Systems in the area of long range surveillance, tracking, and camera handoff
- Will automatically extract "soft biometric" information from subjects for the purposes of low-bandwidth multi-sensor tracking
- Identification can be performed as subjects are detected and tracked throughout the imagery
  - Automatically – once a subject is detected, the user can double click on their image to send it to recognition
  - Manual – The operator selects a head in the video and runs that individual through the face recognition process
- Note: For accurate surveillance recognition, our modules require at least 40 pixels between the eyes

Objective #3 – Met Successfully

Web Services Interface



- Developed a common Web Services / SOA interface for low bandwidth requests & responses across a network
- All code developed in .NET 2.0 to meet requested MARS interface requirements
- Remote / Alternative Facial Database functionality provided through MySQL connectivity

Objective #4 – Met Successfully

Graphical User Interface

- Enrollment GUI
  - A functional mockup of the enrollment capability that is available to be integrated into the existing BAT system or system of choice
  - Allows the operator to load previously acquired images and adjust automatic landmark detection if necessary
- Gallery Browser
  - Allows the operator to load and search the list of currently enrolled subjects in the database
- Surveillance GUI
  - As the 2D/3D face recognition process is refined, we want to transition this software to perform automatic non-cooperative perimeter surveillance and border control
    - Accomplished through the use of IP Video feeds and automatic subject detection and tracking at long range
- Recognition GUI
  - Once a probe face is acquired (either from surveillance or from a user request), recognition can be performed
  - Shows the top X matches in the dataset and allows the user to browse the enrolled images (and 3D representations) of the potential subjects

Objective #5 – Met Successfully

Enrollment GUI

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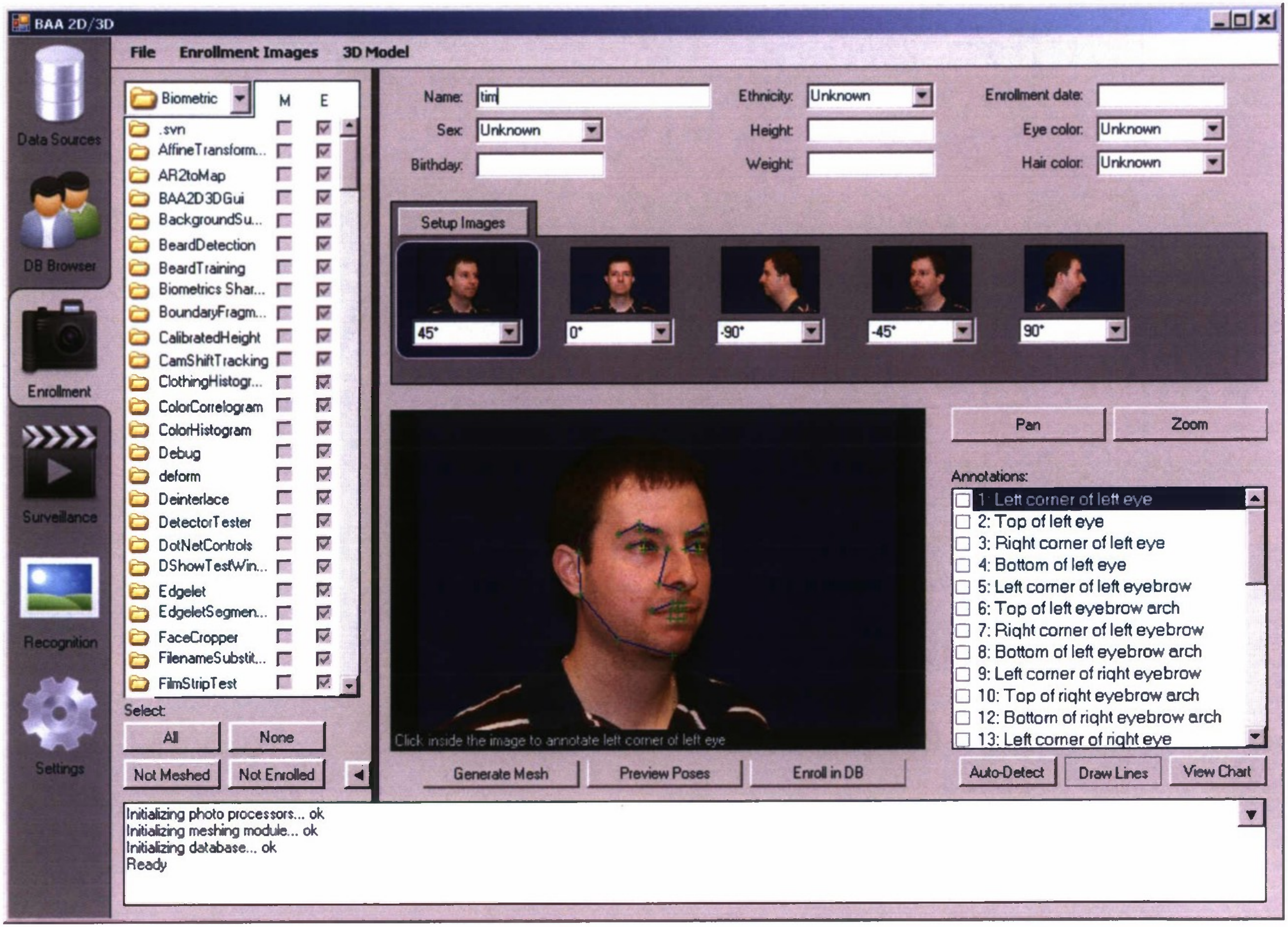

Gallery Browser

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Surveillance GUI

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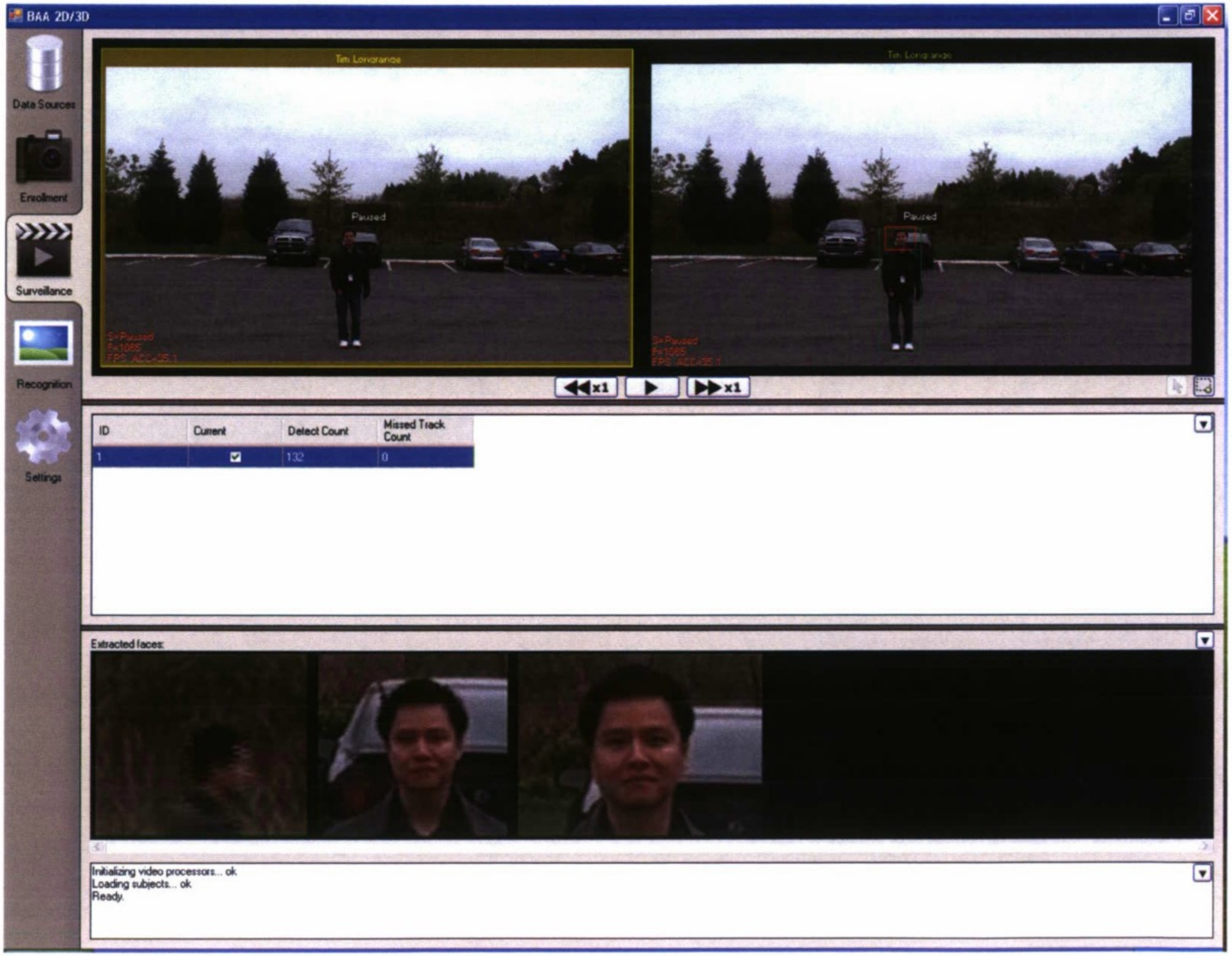

Recognition GUI

Summary & Demonstration

- Presented the result of significant research and development in the area of non-cooperative 2D/3D facial recognition
- Successfully developed multiple ways of creating accurate 3D models using between 1 and 5 2D images
- Created a modular application able to demonstrate the capabilities of multiple current research areas
  - 3D Facial Reconstruction
  - Long Range Subject Detection & Tracking
  - Frontal / Non-Frontal Facial Matching
  - Soft Biometric Feature Extraction

All Objectives Successfully Met!

Project Questions / Discussion

- Any questions on system operation and/or performance?
- Do you see an opportunity for integration into existing Army system(s)?
- Is there any potential future work or areas you would like us to expand on?
- Any key partners we should be working with beyond Oberon and our existing Academic consultants?
- Development support on other initiatives?
  - Intelligent Image Acquisition
  - Automatic Long Range Tracking & Subject Identification
  - 360 Degree Mobile Subject Identification
- See technology demonstration of research developed here at Green Devil – Empire Challenge 10?